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Report to Congressional Requesters

August 1999

SPACE TRANSPORTATION

Status of the X-33 Reusable Launch Vehicle Program

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United States General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

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August 11, 1999

The Honorable Dana Rohrabacher
Chairman
The Honorable Bart Gordon
Ranking Minority Member
Subcommittee on Space and Aeronautics
Committee on Science
House of Representatives

The purpose of the $1.3 billion X-33 Program, cosponsored by the National Aeronautics and Space Administration (NASA) and the Lockheed Martin Corporation, is to develop and demonstrate advanced technologies and techniques needed for future reusable launch vehicles (RLV), including lightweight internal fuel tanks, advanced rocket engines, a durable heat shield, and rapid-turnaround, low-cost operations. The X-33 vehicle will be a half-scale model of Lockheed Martin's planned single-stage-to-orbit (SSTO) Venture Star RLV, an operational vehicle that will be based on and developed after the X-33. Lockheed Martin and NASA will base the decision to proceed with developing the Venture Star, in part, on the results of the X-33 Program. NASA would potentially be one of Lockheed Martin's primary customers for the cargo-only flights and, at this time, is the only anticipated customer for passenger flights. The passenger flights would carry crewmembers to and from the International Space Station.

NASA and Lockheed Martin are conducting the X-33 Program under a cooperative agreement,[1] a financial instrument with which a government entity and one or more public or private organizations jointly fund and implement an activity to achieve common objectives. Such a partnership was encouraged by the National Space Transportation Policy of 1994 as a means of (1) establishing NASA as the lead agency for technology development and demonstration of reusable space transportation systems and (2) positioning the government and the private sector to make decisions on the development of an operational, reusable launch system. Under the X-33 cooperative agreement, NASA's contribution is

[1] Lockheed Martin has made agreements with Allied Signal Aerospace, B.F. Goodrich Aerospace, Boeing-Rocketdyne Division, and Sverdrup Corporation to assist in the X-33 Program.

$912.4 million, and the current estimate of Lockheed Martin's and its industry partners' contributions is $286.6 million.

Because of the Subcommittee's concerns about technical difficulties encountered by the X-33 Program, you asked us to review the progress of the program. As agreed with your offices, we (1) determined whether the X-33 Program is meeting the cost, schedule, and performance objectives established in the X-33 cooperative agreement, (2) determined how NASA's oversight responsibility was changed by the cooperative agreement, and (3) identified potential issues NASA may face as it moves toward a decision on whether to use Venture Star RLVs to service the International Space Station.

Results in Brief

NASA and Lockheed Martin X-33 program managers anticipate that the program will achieve technical requirements such as demonstrating the feasibility of building large liquid hydrogen fuel tanks made of graphite composite material.[2] However, the program will not meet some original cost, schedule, and performance objectives. Problems encountered by Lockheed Martin while working toward the X-33 Program's technical requirements have caused cost increases, delay of the test vehicle's first flight, and revision of some performance objectives. The technical problems occurred during development and fabrication of the X-33 vehicle's internal fuel tanks, rocket engines, and thermal protection system, the three key advanced technologies the program seeks to demonstrate. Resolving these technical problems caused Lockheed Martin's estimated contribution to grow $75 million above the original estimate of $211.6 million, to $286.6 million. However, part of the increase will be borne by the government. Procurement regulations allow companies to recover allowable independent research and development costs by including them as overhead in the pricing for other government contracts. Thus, Lockheed Martin's and its partners' shares may actually be lower. In addition, estimated government costs for NASA civil service personnel working on the program not included in NASA's X-33 program budget also increased. Together, these estimated costs increased from $216.9 million to $274.3 million as of March 1999. As a result, we believe a more accurate representation of the estimated government's share of the X-33 Program is $1.23 billion, while industry's estimated share is $125.4 million.

[2] Graphite composite is a high strength, low-weight material used to reduce structural weight by replacing heavier metal components.

As a result of the technical problems, the first flight of the X-33 vehicle was delayed 16 months, from March 1999 to July 2000. Importantly, this could delay NASA's decision about whether to invest in space shuttle fleet upgrades or rely on new launch vehicles such as Venture Star. The technical problems and schedule constraints also resulted in changes to program performance objectives, including a reduction of the test flight speed for the X-33 vehicle.

To implement the terms of the X-33 cooperative agreement, NASA assigned to Lockheed Martin the leadership role in executing the X-33 Program. Under the agreement, NASA monitors and verifies the program's progress and makes payments to Lockheed Martin when milestones are met. NASA also provides personnel and facilities at its field centers to perform technical tasks for the program under the direction of Lockheed Martin. An inherent characteristic of the cooperative agreement is the way in which NASA conducts program oversight. According to NASA's X-33 program manager, the agency's oversight is different from that used for traditional development contracts, as it relies on insight gained from NASA employees working alongside Lockheed Martin personnel. NASA's Advisory Council, Program Management Council, and the Office of Inspector General also periodically oversee the program and have reported technical and management problems.

Several issues will need to be evaluated before NASA decides to use Venture Star RLVs to support the International Space Station. First, the results of the X-33 Program must provide sufficient information for NASA to determine that the risks have been sufficiently reduced and that continuation of activities leading to the agency's use of Venture Star as a customer is warranted. Second, even though Venture Star RLVs are intended to be commercially owned and operated, government financial incentives will likely be needed to initiate such a venture. Third, NASA would have to pay for either two crew modules or modifications to Venture Star vehicles if the crew return vehicle being developed for the International Space Station is chosen as a means for Venture Star to carry people. Fourth, because the Venture Star RLV would not carry as much cargo as the space shuttle, additional flights would be needed. The more frequent docking activities may reduce the amount of stable time available for some science operations.

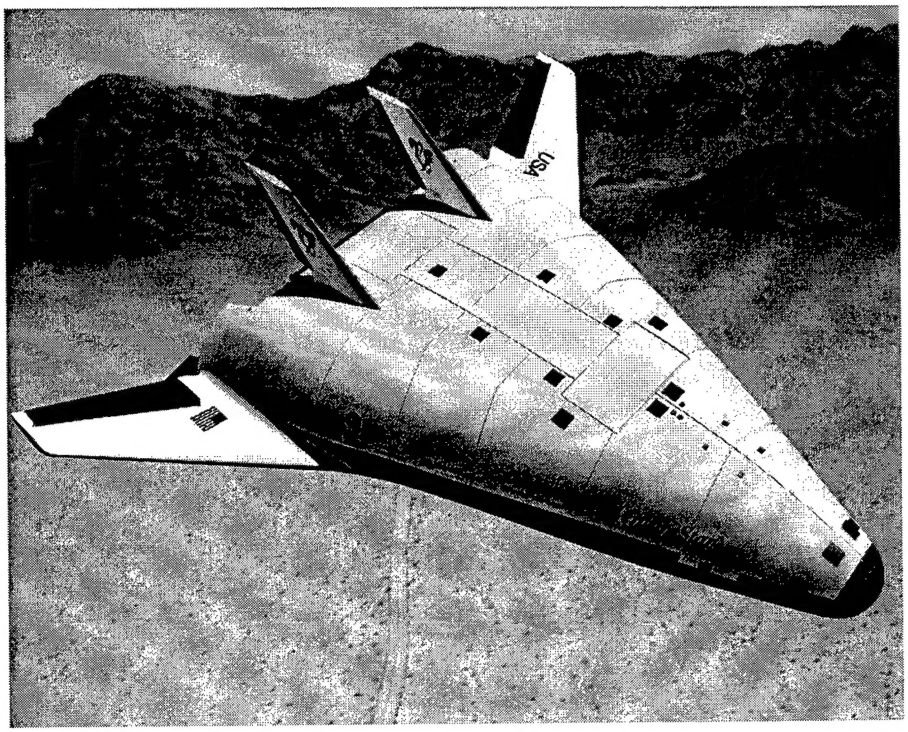
The Government Performance and Results Act of 1993 requires that federal agencies prepare annual performance plans that establish measurable objectives and performance targets for major programs. NASA's Fiscal

Year 2000 Performance Plan does not include performance targets that establish a clear path leading from the X-33 flight-test vehicle to an operational SSTO vehicle. Ensuring that results from the X-33 Program adequately support a confident decision to develop an SSTO vehicle such as the Venture Star deserves attention in NASA's performance plan. We provide a recommendation to that effect.

Background

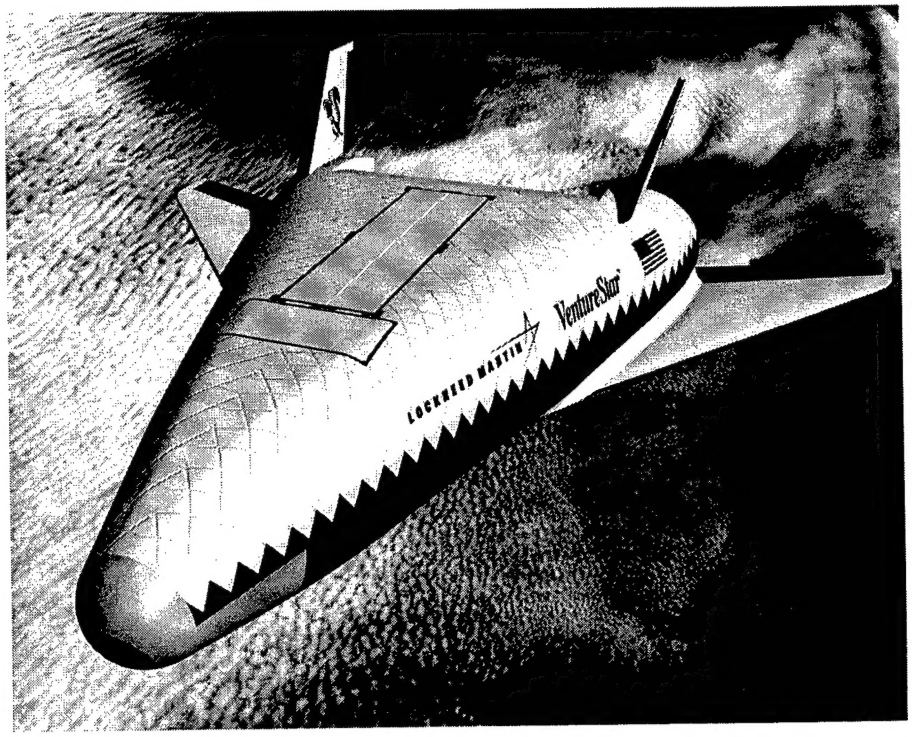
The X-33 Program is a key goal of NASA's strategy to reduce launch costs from $10,000 per pound on the space shuttle to $1,000 per pound to low earth orbit by using SSTO RLVs. After a competitive conceptual design phase, NASA, in July 1996, signed the X-33 cooperative agreement with Lockheed Martin for the design, development, and flight-testing of the company's X-33 advanced technology demonstration vehicle. To achieve this goal, NASA has established technical and performance objectives for the X-33 Program that the agency believes will lead to development of SSTO RLVs such as Venture Star. The technical objectives of the X-33 Program are to develop and demonstrate the use of lightweight composite materials for internal liquid hydrogen fuel tanks, linear aerospike rocket engines, a durable thermal protection system, and aircraft-like operations. The performance objectives are to demonstrate the technologies by flying the X-33 vehicle and measuring its performance characteristics. The flight-test program requires the vehicle to make at least five flights and meet specific performance and technical requirements needed to validate key RLV technologies. Figure 1 is an illustration of the planned X-33 vehicle, and figure 2 is an illustration of the planned Venture Star vehicle.

Figure 1: Exterior Illustration of the Planned X-33 Vehicle



Source: NASA.

Figure 2: Exterior Illustration of the Planned Venture Star Vehicle



Source: NASA.

To demonstrate the technologies and low-cost operations needed for SSTO RLVs, the X-33 vehicle will be flown under autopilot in a series of suborbital flight-tests from Edwards Air Force Base in California to the Michael Army Airfield in Utah. Longer flights to Malmstrom Air Force Base in Montana are also planned. The program is scheduled for completion in December 2000.

Impact of Technical Problems on Program Cost, Schedule, and Performance Objectives

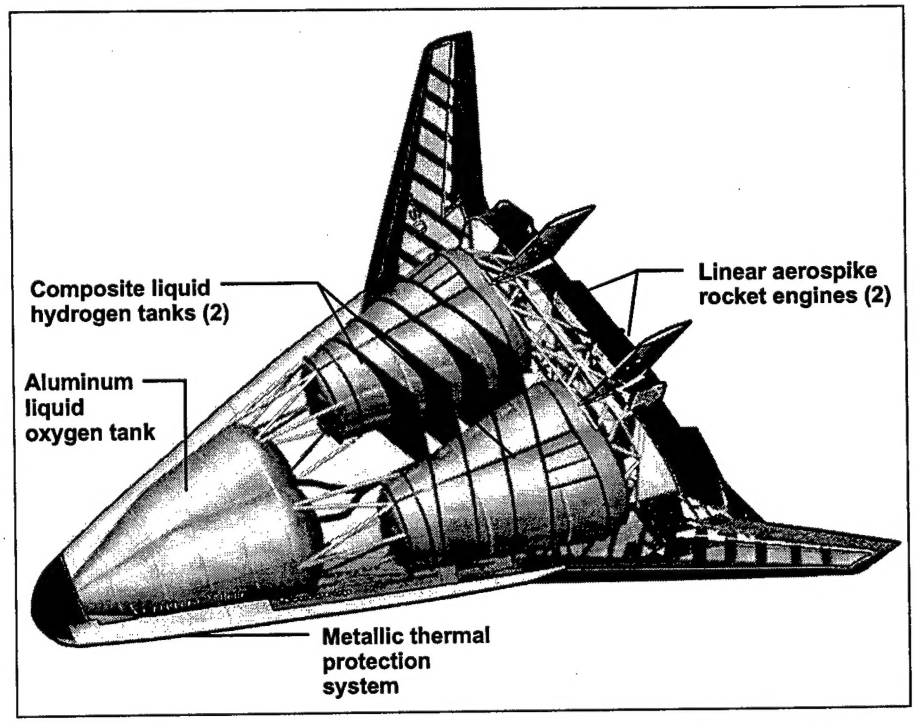
As a result of problems encountered while working toward the program's technical requirements, Lockheed Martin's estimated contribution to complete the X-33 cooperative agreement increased. However, part of the increase will be borne by the government. Some of Lockheed Martin's and its industry partners' contributions could be considered independent research and development costs and are potentially recoverable through pricing on other government contracts. Further, the X-33 vehicle's

flight-testing was delayed and some performance objectives were changed. NASA and Lockheed Martin officials believe that despite the problems, the X-33 Program will meet its original technical requirements and completion date in December 2000.

Primary Technical Difficulties

The X-33 Program experienced technical difficulties with each of the three key technologies under development for the Venture Star RLV: the internal composite liquid hydrogen fuel tanks, the linear aerospike engines, and the durable thermal protection system (heat shield). Figure 3 shows a cutaway illustration of the X-33 vehicle's major subsystems, including the tanks, rocket engines, and heat shield. The first major technical problem arose during fabrication of the first of two internal composite liquid hydrogen tanks. Sections of the tanks are made by bonding together layers of composite materials. The sections are then bonded together to form lobes, or quarter sections, which are, in turn, bonded together to form the tanks. Difficulties were encountered in bonding two lobes onto a y-shaped joint in the left-hand tank. The affected surface layers of the lobes were repaired and reapplied to the joint. However, during the rebonding process, the composite surface layers of the two lobes disbonded over large portions of the lobes. The affected lobes were removed, and two new lobes were fabricated and are being installed on the tank. The right-hand internal hydrogen fuel tank did not experience such fabrication difficulties and is currently undergoing qualification tests at NASA's Marshall Space Flight Center.

Figure 3: Cutaway Interior Illustration of the Planned X-33 Vehicle



Source: NASA.

The second major technical problem occurred while fabricating one of the exhaust ramps for the linear aerospike rocket engines. Ten such ramps are being made for the program. The exhaust ramps are made of layers of copper alloy brazed together. Impurities in the brazing material caused the layers of one ramp to disbond during the fabrication process. Two ramps have been produced successfully since the problem occurred, according to NASA and Lockheed Martin program managers.

The third technical problem occurred during fabrication of the thermal protection system. The thermal protection system is composed of individual heat-resistant metallic panels attached to the bottom and leading edges of the vehicle's exterior surfaces. The individual panels are made by bonding together several layers of heat-resistant materials. Difficulties encountered in bonding together the layers of the panels during the fabrication process led to a high rejection rate and increased the amount of time needed to make the panels. The panel fabrication process has been improved, according to NASA and Lockheed Martin program managers.

Production of the flat panels for the bottom of the vehicle is complete, and most of the large curved panels for the vehicle's leading edges have been made. Bonding the layers of the smaller curved panels, which are also used on the leading edges, has proven to be the most difficult. These panels are still being fabricated, but are not expected to cause further schedule delays, according to NASA and Lockheed Martin program managers.

Effects on Lockheed Martin's Cooperative Agreement Contributions

As of March 1999, Lockheed Martin estimated that industry's contributions to complete the X-33 cooperative agreement had increased by $75 million, or 35.4 percent, from $211.6 million to $286.6 million. The increases were due primarily to the technical problems discussed above.[3] Table 1 shows the original and current estimated contributions for NASA and Lockheed Martin to complete the X-33 Program as established in the cooperative agreement. NASA's contribution under the cooperative agreement remains fixed at $912.4 million (see note "b" below).

Table 1: Original and Current Estimated Contributions for the X-33 Program

Then-year dollars[a] in millions

	July 1996	March 1999	Changes	Percent changes
NASA program budget[b]	$1,012.2	$1,012.2	0.0	0.0
Lockheed Martin and industry partners' contributions	211.6	286.6	+$75.0	+35.4
Total	**$1,223.8**	**$1,298.8**	**+$75.0**	**+6.1**

[a] Then-year dollars represent the estimated actual value of the funds for a particular year.

[b]NASA's contribution to the X-33 Cooperative Agreement is $912.4 million. The remaining $99.8 million in the program budget is for NASA headquarters costs, related research and development activities, and program office operations.

Lockheed Martin program officials anticipate that industry's estimated contribution to complete the X-33 Program under the cooperative agreement will need to be increased between $10 million and $64 million to resolve the existing technical problems. Lockheed Martin has not yet formally revised the industry team's estimated contributions to reflect any such increase. NASA and Lockheed Martin are implementing cost

[3] The allocation of cost increases associated with individual problems is not discussed due to the proprietary nature of the information.

reduction strategies to limit the increases by deleting some Venture Star development tasks and reducing Lockheed Martin's X-33 workforce. The final cost of the program will depend on the results of Lockheed Martin's current cost-control efforts and the cost to resolve any future technical problems.

Effects on Total Government and Net Industry Contributions

Under the terms of the cooperative agreement, NASA's contribution to the X-33 development program remains fixed, and Lockheed Martin and the industry partners are responsible for all cost growth. However, at least some cost growth may be recovered by Lockheed Martin and the industry partners by including the costs in their pricing for other government contracts. Further, costs for NASA personnel working on the X-33 Program are paid from other NASA budgets. Thus, the government's share of the costs for the X-33 Program is greater than that represented in the cooperative agreement.

First, as recognized in the agreement, Lockheed Martin and its industry partners plan to recover portions of their contributions by classifying them as independent research and development (IRAD) expenses and then including them as overhead in other government contracts. Federal acquisition regulations[4] allow companies to recover IRAD costs by including such expenses as overhead in pricing of other government contracts. Because Lockheed Martin has contracts with other government agencies, such as the Department of Defense, those agencies' budgets may bear some of these costs. Lockheed Martin and its partners plan to recover from the government an estimated $161.2 million of their estimated $286.6 million contribution to the agreement. Thus, as shown in table 2, Lockheed Martin's and the industry partners' potential net contribution for the X-33 Program could be as low as $125.4 million. However, an audit or review must be conducted to determine the portion of the contributions allocable as overhead on other government contracts. Additional increases in industry's contributions to the X-33 Program will also potentially increase the amount of IRAD reimbursements the partners receive from the government.

[4] Federal Acquisition Regulation 31.205-18—Independent Research and Development and Bid and Proposal Costs.

Table 2: Estimated Total Industry Contribution for the X-33 Program, Factoring in Potential IRAD Reimbursements

Then-year dollars in millions

	July 1996	March 1999	Changes	Percent changes
Total contribution to cooperative agreement	$211.6	$286.6[a]	+ $75.0	+ 35.4
Potential government IRAD reimbursement	121.7	161.2[b]	+ 39.5	+ 32.5
Net industry contribution	**$89.9**	**$125.4**	**+ $35.5**	**+ 39.5**

[a]Industry partners' contributions to the cooperative agreement will increase between $10 million and $64 million to resolve the program's technical problems, according to a Lockheed Martin official.

[b]Government reimbursements of industry IRAD costs will increase by an estimated $5 million to $32.5 million, depending on how much the industry partners' contributions grow, according to a Lockheed Martin official.

Second, costs not in the X-33 cooperative agreement or NASA's X-33 program budget include salaries, benefits, and support services for the government personnel working on the program at various NASA centers. These personnel costs will be paid out of another NASA budget account. As shown in table 3, the current estimate is $113.1 million as of March 1999. The government's final share of the program's total cost also depends on the amount of IRAD costs determined to be recoverable, the results of Lockheed Martin's cost control efforts, and the nature of any future technical problems.

Table 3: Estimated Total Government Costs for the X-33 Program, Factoring in Potential IRAD Reimbursement and Personnel Costs

Then-year dollars in millions

X-33 Cost elements	July 1996	March 1999	Changes	Percent changes
NASA X-33 program budget	$1,012.2	$1,012.2	$0.0	0.0
Potential government reimbursement of industry IRAD[a] costs	121.7	161.2[b]	+ 39.5	+ 32.5
Government personnel costs[c]	95.2	113.1	+ 17.9	+18.8
Sub-totals of government costs outside X-33 budget	**216.9**	**274.3**	**+ 57.4**	**+ 26.5**
Total government costs	**$1,229.1**	**$1,286.5**	**+ $57.4**	**+4.7**

[a]Independent research and development

[b]Government reimbursements of Lockheed Martin and its partners' IRAD costs will increase by an estimated $5 million to $32.5 million, depending on how much of the estimated $10 million to $64 million cost increase is realized, according to a Lockheed Martin official.

[c]These costs are estimates through completion of the program and include salaries, benefits, training, and travel costs.

First Test Flight Delays

Problems encountered during fabrication of the engines and one of the internal liquid hydrogen fuel tanks led to a 16-month delay of the first test flight of the X-33 vehicle, from March 1999 to July 2000. However, the program's December 2000 completion date remains unchanged. Lockheed Martin has maintained the original X-33 Program completion date by reducing Venture Star design and development work that the company had planned to accomplish during the X-33 Program. Table 4 shows the original date for the first flight and subsequent changes and the associated delay of the first flight date. Although problems in fabricating the thermal protection system panels delayed delivery milestones of the panels, the delay did not cause a delay in the first flight schedule because the schedule had already been delayed by the engine and fuel tank problems.

Table 4: X-33 Program Schedule Changes

Program milestones	Original milestone date	First revised date	Second revised date	Third revised date
Liquid H_2 tank delivery complete	Dec. 1997	Oct.1998	Mar.1999	July 1999[a]
Aerospike engines delivery complete	Aug.1998[b]	Feb.1999	Sept.1999	Oct.1999[c]
First X-33 flight-test	Mar.1999	July 1999	Dec.1999	July 2000

[a]For the left-hand fuel tank. The delivery date for the right-hand tank was May 1999.

[b]For the second of two flight engines.

[c]For delivery of both engines.

Delays in the X-33 Program may affect NASA's investment plans for future space-launch programs, including decisions on whether and when to upgrade the space shuttle fleet or rely on a new launch vehicle, such as the Venture Star RLV. NASA originally planned to decide in 2000 whether to upgrade the space shuttle fleet and, if so, which upgrades to implement. NASA now plans to make its recommendations for a future space transportation investment strategy as part of the fiscal year 2001 budget process, which starts in the later part of 2000.

Performance Objectives Revised

Technical problems and schedule constraints led Lockheed Martin and NASA to change two X-33 Program objectives and flight-test milestones. First, Lockheed Martin and NASA chose to use an internal liquid oxygen tank made of aluminum for the X-33 vehicle, instead of the lightweight composite materials used for the internal liquid hydrogen tank. Schedule constraints early in the program led Lockheed Martin to exercise its option under the cooperative agreement to use an internal oxygen tank made of aluminum instead of the lightweight composite materials used for the internal liquid hydrogen tank. An operational Venture Star RLV will likely require a lightweight composite liquid oxygen tank to reduce the vehicle's weight and achieve SSTO operations. The X-33 Program plans to demonstrate the primary elements of this technology by building a small-scale 10-foot-diameter composite liquid oxygen tank that will be tested on the ground.

Second, the test flight speed objective was reduced from Mach[5] 15 to Mach 13.8. According to Lockheed Martin and NASA X-33 program managers, the maximum flight-test speed was reduced because the detailed design phase of the program determined that the vehicle's projected weight

would exceed design requirements and prevent it from reaching Mach 15. After reviewing the vehicle's design and the technical objectives for the flight-tests, a panel of experts convened by NASA concluded that the flight-test technical objectives could be achieved at a lower speed. Lockheed Martin and NASA program officials told us that weight reduction measures have already been incorporated into the preliminary design of the Venture Star RLV to meet the vehicle weight requirements.

The weight reduction measures are based on lessons learned designing and building the X-33 test vehicle. One of the weight-saving modifications is to attach the Venture Star vehicle's thermal protection system panels directly to the vehicle's interior structure and fuel tanks, eliminating the weight of the attachment structures used on the X-33 vehicle. Other weight-reducing modifications for the Venture Star RLVs include lighter weight composite and ceramic engine components and composite internal liquid oxygen tanks. Although the composite and ceramic components have not been demonstrated, NASA and Lockheed Martin plan to reduce the technical risks of providing these technologies for the Venture Star RLVs through ground-based demonstrations during the X-33 Program.

In addition to the revised performance objectives, the scheduled length of the X-33 flight-test program was reduced from 10 to 3 months, and the original single program flight-test milestone and payment schedule were changed so that there are now three flight-test milestones and payments. The original flight-test program required Lockheed Martin to obtain specific technical data and demonstrate rapid and efficient aircraft-like operations in 15 test flights over a 10-month period. Upon completion of these objectives, NASA was to pay the company a $75-million payment for successfully completing the flight-test program. The current program plan provides for a $60-million payment after the technical data and vehicle operations objectives are achieved, and the vehicle has flown at least five flights. After the initial flight-test objectives have been achieved, NASA will pay the company $10 million if it completes five more flights, and another $5 million if it completes the last five flights. According to NASA's X-33 program manager, the additional flights will further demonstrate rapid and low-cost RLV operations and build investors' confidence that privately financed RLVs are feasible.

[5] Mach numbers represent speed measured as units of the speed of sound, which is 741 miles per hour at sea level. For example, Mach 2 equals 1,482 miles per hour.

The changes to the X-33 flight-test program were made in order to reduce the risk that Lockheed Martin would receive no payment if the company achieved all of the technical and operational objectives but did not complete all of the planned 15 test flights. The required technical data will be obtained by observing, recording, and analyzing the vehicle's behavior during and after the test flights. Demonstration of aircraft-like operations requires that the X-33 vehicle fly one 2-day turnaround flight and two consecutive 7-day turnaround flights. Although the scheduled flight-test program is now only 3 months long, flight-tests will continue longer if needed to achieve program objectives, according to NASA's X-33 program manager.

NASA's and Lockheed Martin's Financial and Oversight Roles

According to NASA program officials, the X-33 cooperative agreement establishes a partnership business relationship between NASA and Lockheed Martin. Changes to the cooperative agreement require bilateral agreement. The agreement assigns to Lockheed Martin responsibility for managing and implementing the X-33 Program but also permits substantial involvement of NASA personnel in performing various program technical tasks at NASA centers, under the direction of Lockheed Martin. NASA's oversight of the X-33 Program is different from that used for traditional government contracts, as it relies on insight gained from NASA employees working alongside Lockheed Martin personnel.

Lockheed Martin and NASA Financial Obligations and Roles

NASA used a cooperative agreement instead of a traditional contract, in part, to reduce its financial risk by capping its contribution. Through the agreement, NASA seeks to facilitate the creation and commercialization of a low-cost space-launch service industry, of which NASA would be a major customer. The cooperative agreement defines each party's roles and responsibilities in conducting the program. Lockheed Martin is to provide 22.1 percent of the funding, define the X-33 vehicle's technical and performance requirements, and, with inputs from its industry partners and NASA, design and build the vehicle. Lockheed Martin will also conduct flight-tests of the X-33 vehicle and decide with NASA whether to build a fleet of two operational Venture Star RLVs. This decision will be based, in part, on criteria developed by the Office of Science and Technology Policy, the Office of Management and Budget, NASA, and Lockheed Martin.

Agreement Establishes Oversight Approach

An inherent characteristic of the cooperative agreement is the way in which NASA conducts oversight of Lockheed Martin's work on the X-33 Program. The cooperative agreement enables NASA to obtain insight into the program, according to the NASA program manager. In traditional research and development contracts, NASA sends personnel to contractor facilities to perform an extensive review of whether the contractor performed its assigned tasks in accordance with contract specifications. Under the X-33 cooperative agreement, insights are gained through NASA technical personnel working alongside personnel from Lockheed Martin and other industry partners. This ongoing involvement in the work enables NASA to obtain real-time and detailed insight into program activities. As an example, NASA's X-33 program manager cited the situation where NASA became aware that layers of one lobe of the X-33 vehicle's internal composite hydrogen fuel tank had unbonded on December 24, 1998, the day after the problem occurred in Sunnyvale, California.

NASA's primary oversight activities for the X-33 Program consist of program office monitoring of Lockheed Martin's progress in meeting program milestones and verifying that the company has achieved the milestone performance requirements specified in the cooperative agreement before payments are made. NASA's Advisory Council, Program Management Council, and Office of Inspector General also provide program oversight.

NASA's X-33 program office has taken specific oversight actions in response to problems with the program. For example, since the cooperative agreement provides that milestone payments are made only after performance criteria have been met, independent of when the milestones are scheduled for completion, the program office withholds all subsequent payments until satisfactory accomplishment of the performance criteria. In another case, after several requests to Lockheed Martin for action, the program office notified Lockheed Martin that the agency planned to withhold $500,000 from all subsequent milestone payments because the company's system integration work on the X-33 Program was inadequate. According to NASA's X-33 program manager, Lockheed Martin complied with NASA's request to strengthen the program's system integration function by creating a system engineer position in its program office at the same level as the program manager.

The NASA Advisory Council performs periodic reviews of the X-33 Program. Members of the NASA Advisory Council are volunteers appointed by NASA. The Council reports to the NASA Administrator. At a

recent meeting,[6] Council members discussed concerns about (1) whether there was a clear growth path leading from the X-33 flight-test vehicle to an operational SSTO vehicle and (2) NASA's lack of funding to pursue the shuttle/space station programs and SSTO development at the same time.

The Program Management Council is NASA's senior agency review board and oversees planning, implementation, and management of all major NASA programs. NASA's Associate Deputy Administrator chairs the Council, and senior executives of NASA's functional and staff offices are members. In its most recent review of the X-33 Program, the Council's review team concluded, among other things, that (1) due to technical problems, the program may not be able to meet its technical and performance objectives within current funding and schedule plans; (2) if the program does not achieve its technical and performance objectives, the program may not be able to support an informed decision on the viability of a near-term SSTO RLV; and (3) the program should be completed because of the value provided by the program's planned demonstration of several first-of-a-kind technologies as a system.

In a recent audit report[7] on the X-33 cooperative agreement, the NASA Office of Inspector General found that the agreement had provided NASA with certain benefits, including faster program initiation and greater management flexibility. However, the report also attributed a number of program management problems to the agreement, including lack of full and prompt compliance with some NASA management procedures, inaccurate internal reporting of some program costs, incomplete government property reports, and uncertainty concerning ownership of the X-33 vehicle. In a written response to a draft of the Inspector General's audit report, NASA's Office of Aerospace Technology concurred with all nine recommendations in the report. In response to NASA's comments, the Office of Inspector General stated that the agency's planned and implemented actions were generally responsive to seven of the nine recommendations and that it would request additional comments and information concerning the remaining two recommendations.

[6] NASA Advisory Council Meeting Report Minutes, December 3-4, 1998.

[7] Audit Report: X-33 Cooperative Agreement, NASA Office of Inspector General, IG-99-019, Mar. 29, 1999.

Issues Facing NASA If Venture Star Is Used to Support the International Space Station

Before NASA decides to use Venture Star RLVs to support the space station, it will need to evaluate (1) whether adequate progress has been made in reducing risks by resolving the technical challenges to developing an operational RLV; (2) what government financial incentives, such as loan guarantees, may be needed to assist in developing an operational fleet of Venture Star RLVs; (3) what NASA's costs would be to build at least two crew modules for a RLV to carry crews to and from the space station; and (4) what the effects would be on the maintenance and operation of the space station and its science experiments.

Confidence That X-33 Results Support RLV Development Decision

In 1995 the Office of Science and Technology Policy, the Office of Management and Budget, and NASA jointly established criteria to be used in deciding whether the government should proceed beyond the X-33 Program to support development of an operational SSTO Venture Star RLV. These criteria include (1) demonstration of the X-33 Program's technical objectives, including technical traceability[8] to Venture Star; (2) demonstration that a cooperative government/industry technology development program can be successful and efficient; and (3) establishment of acceptable business arrangements between government and industry that facilitate the development and operation of the next generation of space-launch systems. The criteria envision that the timing of NASA's decision to use the Venture Star coincides, at the end of the decade, with decisions on funding for space shuttle investments needed to continue operations through 2012. The specific technical criteria for proceeding beyond the X-33 Program include requirements that the NASA and industry team use a flight-test vehicle to demonstrate technologies that are scalable to potential SSTO RLV configurations. These configurations include the basic booster design, reusable internal composite or metallic tanks and primary structures, reusable and durable thermal protection system materials, and operational concepts.

NASA's Advisory Council has raised concerns that there may not be a clear growth path leading from the X-33 flight-test vehicle to an operational SSTO vehicle. We share this concern.

[8] Traceability in this case means that X-33 technologies and operational techniques can provide some of the risk reduction needed to eventually build and fly full-scale operational Venture Star RLVs.

The Government Performance and Results Act directs that federal agencies promulgate annual performance plans that describe (1) the agency's performance goals and measures, (2) the strategies and resources to achieve these goals, and (3) procedures to verify and validate reported performance. NASA's Fiscal Year 2000 Performance Plan states that the overall objective of the X-33 Program is to revolutionize space-launch capabilities. The plan also states that the program will demonstrate technologies that (1) are traceable to a mass fraction of less than 10 percent of empty vehicle weight that is required for future RLVs, (2) validate key aerothermodymanic environments, (3) enable the X-33 vehicle to fly faster than Mach 13.8, (4) allow the vehicle to perform one 2-day turnaround flight and consecutive 7-day turnaround flights, and (5) enable the vehicle to be maintained by a 50-person ground crew. The combined results are intended to reduce technical risk in the full-scale development of an operational RLV. However, the only measurable performance target associated with the X-33 Program in the plan is to conduct flight-testing of the X-33 vehicle. No further targets are identified that would provide an indication that NASA can successfully demonstrate that it is on a growth path leading from the X-33 flight-test vehicle to an operational SSTO vehicle.

Government Incentives for Venture Star Vehicles

NASA and Lockheed Martin foresee that the federal government may need to provide financial incentives before Lockheed Martin can begin building Venture Star RLVs. Government incentives could be needed to enable Lockheed Martin to secure affordable private-sector financing of the estimated $7.2-billion cost of building two RLVs and begin flight operations. Borrowing costs for the Venture Star might be relatively high because investors would require a high rate of return due to the technical risks inherent in building a new space-launch vehicle. Government incentives could take several forms, including loan guarantees, or NASA-funded technology development efforts.

If technical risks are not sufficiently reduced by the X-33 Program, additional NASA funding may be needed for further technology development of critical technologies to be used in future RLVs, including the Venture Star. For example, if the X-33 Program has not sufficiently developed the technologies needed for an operational RLV, NASA could approve a limited extension of the program to address technical uncertainties. Further, NASA already plans to fund future research and development programs for RLV technologies. NASA's technology

development efforts to mature SSTO and RLV technologies include the Future-X and Advanced Space Transportation Programs.

Requirement for Venture Star Crew Modules

Lockheed Martin plans to build Venture Star RLVs that initially carry only cargo and begin flights in 2005. Lockheed Martin is designing the Venture Star vehicles primarily to meet the needs of potential commercial customers who want to launch satellites. However, because much of Lockheed Martin's Venture Star projected revenues will come from servicing the International Space Station, the company is exploring design modifications that would enable the vehicles to carry four or five crewmembers. According to NASA's X-33 program manager, if the agency chooses to use Venture Star RLVs to service the International Space Station, NASA would need to obtain either two crew modules, at an estimated cost between $900 million and $1.2 billion, to be carried in the Venture Star cargo bay or two crew transfer/return vehicles being developed for the International Space Station.[9] According to Lockheed Martin, the Venture Star vehicle would automatically rendezvous and dock with the space station, allowing new crewmembers to board the space station and disembarking crewmembers to return to Earth with the vehicle. The company plans to initiate Venture Star passenger service in 2007. Before passenger services could begin, the Venture Star vehicles would have to be evaluated and certified to meet NASA's human space flight safety requirements.

Effect of Venture Star on Space Station Operations

If NASA decides to use Venture Star RLVs for space station servicing missions, disruptions to the station's operations may increase because of the more frequent dockings by Venture Star vehicles. The agency's current projections show that between two and three Venture Star flights would be required to replace each space shuttle resupply mission because the space shuttle can carry heavier payloads.

The space station requires replenishment of supplies such as propulsion fuel, spare parts, food, water, air, and science experiments. Periodic replacement of station crewmembers is also required. NASA currently plans to use an average of five shuttle flights per year to resupply the station and to have some of its partners provide an average of eight

[9] The crew return vehicle for the International Space Station is being considered as an alternative passenger accommodation that would be attached to the exterior of the Venture Star RLVs.

resupply flights per year to the station on other launch vehicles. Additional resupply flights would likely be required to provide the people and materials needed to solve technical problems that may arise aboard the space station.

Each space shuttle can carry 34,200 pounds of cargo, including up to seven people, to the space station. However, in servicing the International Space Station, a Venture Star RLV would be able to carry 25,800 pounds of cargo or three to four people and a small amount of cargo. Also, NASA plans to use shuttle crewmembers on the resupply flights to perform maintenance of the station. According to NASA X-33 program officials, Venture Star RLVs would have to make two to three flights to provide as much cargo, as many people, or as much maintenance support to the space station as a single shuttle flight. The actual number of flights would depend on the mix of cargo, people, and maintenance operations required for a particular mission.

The Venture Star would then require more docking and undocking operations, potentially disrupting some scientific activities aboard the space station. Operations that may be performed on the space station, including the growth of large inorganic and protein crystals, would require that the station be stable and relatively free of vibrations. Docking and undocking operations create vibrations. Although NASA plans to provide stable periods between resupply missions, more frequent docking and undocking operations would reduce the amount of stable time available for conducting scientific operations.

Conclusions

The X-33 Program is intended to provide Lockheed Martin and NASA with sufficient data to decide whether the technical challenges to develop an operational RLV can be resolved. The importance NASA attaches to this program is reflected in the agency's over $1 billion commitment to the X-33 Program. After the X-33 Program is completed, Lockheed Martin, with input from NASA, will decide whether to build and operate at least two Venture Star SSTO RLVs. NASA hopes to realize significant savings by using Venture Star RLVs instead of space shuttles to service the International Space Station. However, before a decision can be made, key issues need to be evaluated, specifically: (1) whether X-33 Program results provide the confidence that risks have been reduced to proceed with the development of the Venture Star, (2) whether and how much government financial incentives would be needed to develop the Venture Star, (3) what NASA's cost to develop passenger modules for Venture Star would be, and

(4) how the adverse effects on station operations and maintenance would be mitigated.

Ensuring that X-33 Program results adequately support a confident decision to develop Venture Star deserves attention in NASA's performance plan. In particular, the plan would be strengthened if it recognizes the importance of securing an indication that the agency is (1) on a growth path leading from the X-33 flight-test vehicle to an operational RLV and (2) making progress toward its objective of significantly reducing launch costs.

Recommendation

In light of NASA's large investment in the X-33 Program and the important role the program plays in NASA's future plans, we recommend that the NASA Administrator include in the agency's Fiscal Year 2001 Performance Plan performance targets for the X-33 Program that establish a clear path leading from the X-33 flight-test vehicle to an operational RLV and show progress toward meeting the agency's objective of significantly reducing launch costs.

Agency Comments and Our Evaluation

NASA's Associate Deputy Administrator provided written comments on a draft of this report. NASA concurred with our recommendation that more specific and measurable performance targets for the X-33 Program should be included in the agency's performance plans. NASA also stated it had some significant differences in opinion and summarized its positions on several issues. For example, NASA commented on the impact of X-33 flight test delays on decisions associated with investing in space shuttle upgrades; the allocation of IRAD costs and the extent they will be reimbursable; and the achievement of program performance objectives.

NASA commented that while there are delays to the flight-test program, the overall X-33 Program remains within the original schedule. As a result, NASA stated that flight delays should not impact decisions associated with investing in space shuttle upgrades. In the draft report provided to NASA for comment, we stated that delays in the X-33 Program may affect NASA's investment plans for future space-launch programs, including decisions on whether and when to upgrade the space shuttle fleet or rely on a new launch vehicle. We continue to believe that the possibility of such an impact still exists. As indicated in this report, one of the key issues facing NASA is whether X-33 Program results provide confidence that risks have

been reduced. We believe that the feasibility of transferring the key technologies demonstrated on the X-33 to an RLV such as the Venture Star cannot be adequately known until flights have been completed and results analyzed. That will be a challenge with a flight-test program that has been reduced from 10 to 3 months.

With regards to the IRAD issue, NASA made two points. First, the agency stated that costs contributed by contractors under cost-shared cooperative agreements with any federal agency are allowable IRAD costs as long as the costs would have been allowed under federal regulations. Consequently, NASA commented that Lockheed Martin is not receiving a unique benefit. Second, NASA stated that the inference cannot be drawn that Lockheed Martin, or its partners, may recover most of their contributions; and that an audit is needed to ascertain the portion of the contributions allocable to government contracts. Regarding the first point made by NASA, we do not suggest that the contractor is receiving a unique benefit. Rather, our purpose in identifying IRAD costs and estimated reimbursements is to provide clarification on the total estimated costs that will be incurred by the government beyond that identified in the X-33 cooperative agreement. As to the second point, our intent was to identify the estimated contribution that will be made by Lockheed Martin and its partners factoring in potential reimbursement of industry IRAD costs. We agree that inference should not be drawn that Lockheed Martin, or its partners, will recover most of their costs; and that actual reimbursement will require an audit or review to ascertain the portion of the contribution allocable to government contracts. We have modified the text to reflect the need for such an audit.

NASA also commented that it is inappropriate to imply that the X-33 performance objectives have been reduced. The agency stated that the initial objectives were embodied in the cooperative agreement notice used to initiate the program. NASA stated that specific technical and operations technology requirements identified were (1) a minimum of fifteen X-33 flights under main rocket power, (2) a minimum of two flights that meet or exceed a Mach number of 15, (3) demonstration of a 7-day turnaround on a minimum of three consecutive flights, and (4) demonstration of a 2-day turnaround at least once. NASA indicated that specific technical criteria were later established in May 1998. At that time, NASA determined that such criteria could be satisfied at a lower Mach number. Changes were also made, NASA further stated, to break up the flight program into three blocks. We believe the report accurately presents the history and status of these X-33 program performance objectives. In discussing the impact of

technical problems on the X-33 Program performance objectives, our report identifies both the allowable change to an aluminum liquid oxygen tank and the reduction in flight speed. Our report is consistent with NASA's position. We clearly state that the X-33 Program may demonstrate the technical, operations, and business feasibility of a SSTO RLV, but at a lower speed. In addition, our report provides information regarding the breaking up of the flight program and associated payment conditions.

NASA also provided technical comments that we incorporated where appropriate. NASA's written comments and our full evaluation are presented in appendix I.

Scope and Methodology

To determine whether the X-33 Program is meeting its original cost, schedule, and performance objectives, we interviewed officials at NASA headquarters, NASA's Marshall Space Flight Center, Huntsville, Alabama, and at the NASA X-33 program office at Palmdale, California. We also spoke with Lockheed Martin officials at the company's X-33 program office at Palmdale. To determine how NASA's oversight responsibility was changed by the cooperative agreement, we interviewed officials at NASA headquarters, the X-33 program office, and Lockheed Martin officials at the company's X-33 program office. We reviewed the X-33 cooperative agreement, regulations concerning NASA's use of a cooperative agreement for the X-33 Program, NASA and Lockheed Martin documents pertaining to the management and execution of the X-33 Program, and reports issued by the NASA Office of Inspector General and the NASA Advisory Council. To identify potential issues facing NASA if the agency decides to use Venture Star RLVs to service the International Space Station, we interviewed officials at NASA's Headquarters; Langley Research Center, Hampton, Virginia; and the X-33 program office. We also spoke with Lockheed Martin officials at the company's X-33 program office. We reviewed NASA planning documents pertaining to the space shuttle and International Space Station programs. We did not attempt to verify the data provided by NASA and Lockheed Martin.

We conducted our review from November 1998 to June 1999 in accordance with generally accepted government auditing standards.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 14 days from its issue date. At that time, we will send copies to the Chairmen and Ranking Minority Members of the

Senate Committee on Commerce, Science and Transportation; the Subcommittee on Science, Technology and Space, Senate Committee on Commerce, Science and Transportation; and the House Committee on Science. We will also send copies to the Administrator of NASA and the Director of the Office of Management and Budget. We will also make copies available to other interested parties on request.

Please contact me at (202) 512-4841 if you or your staff have any questions concerning this report. Key contributors to this assignment were Jerry Herley, Jeffery Webster, and Lorene Sarne.

Allen Li
Associate Director
Defense Acquisitions Issues

Comments From the National Aeronautics and Space Administration

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001

JUL 1 1999

Mr. Allen Li
Associate Director
Defense Acquisitions Issues
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Li:

Thank you for your letter dated June 9, 1999, to Administrator Daniel S. Goldin. Enclosed are NASA's comments on the draft report titled Space Transportation: Information on X-33 Reusable Launch Vehicle Program (GAO/NSIAD-99-176).

See p. 22.

NASA concurs with the recommendation to include in the Agency's FY 2001 Performance Plan, performance targets for the X-33 Program which establish a clear path leading from the X-33 flight-test vehicle to an operational RLV and show progress toward meeting the Agency's objective of significantly reducing launch costs. While the audit by GAO was very professional and constructive overall, the report highlights some significant differences in opinion on several basic concepts. The comments summarize our position and are intended to clarify some issues that might otherwise be misinterpreted.

If you have any questions or need additional information concerning our comments, please contact Mr. Phil Sumrall at (202) 358-4474. The staffing required to support this response took approximately 135 hours.

Sincerely,

J. R. Dailey
Associate Deputy Administrator

Enclosure

NASA Response to the GAO Draft Report on Space Transportation: Information on X-33 Reusable Launch Vehicle Program, Assignment No. 707362

See p. 22 & comment 1, p. 33.

Program Decision Objectives:
The X-33 Program objectives are to support the decision at the end of the decade whether to proceed with the privately financed development and commercial operation of a single stage to orbit reusable launch vehicle (rocket). Within the original period of performance of the Cooperative Agreement (July 2, 1996 through December 31, 2000), the X-33 Program will achieve its objectives to demonstrate the technologies necessary to reach a decision to proceed with a full scale reusable launch vehicle. While there is a delay of the flight test element of the program, the overall X-33 Program remains within the original schedule. Consequently, the flight delays should not impact decisions associated with investing in Space Shuttle upgrades.

See p. 23 & comment 2, p. 33.

Independent Research and Development (IR&D):
It is Government-wide policy that costs contributed by contractors under cost-shared cooperative agreements with any federal agency are allowable IR&D costs as long as the costs would have been allowed under the cost principle at FAR 31.205-18 in the absence of a cooperative agreement. The Lockheed Martin team is not receiving a unique benefit under the X-33 cooperative agreement. Also, that these costs are recoverable as contract costs from any federal agency that may be a customer of the contractor is true for any allowable indirect cost.

However, the general rule is that IR&D costs are allocated as a general and administrative (G&A) expense in accordance with the company's approved accounting system. Depending upon the extent to which the IR&D costs benefit profit centers of the company, the IR&D costs must be allocated through G&A of these profit centers or through the corporate G&A, as appropriate. The inference that Lockheed Martin, or its industry partners, may recover most of their contributions under the X-33 agreement as an IR&D expense cannot be drawn. An audit or additional review is needed to ascertain the portion of this contribution which in fact may be allocable to government contracts.

See comment 3, p. 33.

Full Cost Accounting/Budgeting:
The Source Selection Official and his Senior Advisory Board, which included the NASA General Counsel, the NASA Comptroller, and the Associate Administrator for Procurement, were briefed on evaluation results of proposals for X-33 Phase II. This briefing also included estimates of Full Cost Accounting implications for NASA civil service personnel proposed in support of each competitor's program. The estimate presented for the full cost accounting delta on the Lockheed Martin proposal was $120M.

1

Historically, in the absence of full cost accounting, these civil service personnel costs are excluded from the program's R&D budget and captured under the NASA Research & Program Management (R&PM) budget which is NASA's existing fund source for salaries and benefits. NASA and other government agencies are currently restricted from reimbursing R&PM costs with funds appropriated for R&D.

See comment 4, p. 33.

NASA Program Management (Relationship/Oversight):
Government insight, not oversight, is gained through the NASA X-33 Program Office performing as a full-fledged partner co-located at the performing industry site. The X-33 Program is a fast-paced, highly visible program within NASA and therefore reports to the NASA Program Management Council (PMC). The X-33 Program is also reviewed frequently by various internal and external independent groups to assist NASA management, the Administration and the Congress in their understanding of the X-33 Program progress.

The cooperative agreement is used as the primary tool for creating a partnership with industry. The cooperative agreement requires significant effort to be accomplished by the government. The government is a key partner with negotiated task agreements established for each NASA Center and DoD installation participating in this program. As such, individuals within government labs perform X-33 Program critical path efforts.

As a part of the business technology demonstration within the X-33 Program, this cooperative agreement is employed here to demonstrate business practices that are essential to the goal of privately financed and commercially operated RLV's. This program assigns the recipient, Lockheed Martin, lead responsibility for execution of the program and day-to-day budget decisions, as encouraged by various members of Congress, including the current Chairman of the Space and Aeronautics Subcommittee, Committee on Science, United States House of Representatives.

The NASA Program Manager is responsible to assure the program objectives are met and that the Government's investment is properly utilized in safely demonstrating technologies that can result in a significant reduction in the cost of access to space, and a significant improvement in the safety and reliability.

See p. 23 & comment 5, p. 33.

Performance Objectives:
The overall performance objectives of the X-33 Program are to demonstrate technical, operations, and business feasibility of a privately financed and commercially operated Single Stage To Orbit RLV. The initial statement of these objectives were embodied in two elements of the Cooperative Agreement Notice (CAN) that was utilized to initiate the X-33 Phase II Program. From an overall perspective, the selection criteria in the CAN provides the primary goal of the program: "A program that supports the decision at the end of the decade to proceed with the privately financed development and commercial operation of a single stage to orbit reusable launch vehicle (rocket)". Additionally, the specific technical and operations technology requirements that enveloped all industry

competitive concepts were specified in the Mandatory (Flight) Milestone description in the CAN. These include: 1) minimum of fifteen X-33 flights under main engine rocket power, 2) a minimum of two X-33 flights that meet or exceed a Mach number of 15, 3) demonstration of a seven day turn around from landing to reflight on a minimum of three consecutive flights, and 4) demonstration of a two day turn around from landing to reflight at least once. Once the competition resulted in the selection of a specific industry concept, the specific technical performance criteria, unique to that concept, was required. The X-33 Program Manager formed an independent team to define these criteria. These criteria were incorporated in the Cooperative Agreement at the time of the program's rebaselining effort in May 1998. While these criteria can be satisfied at a Mach number lower than fifteen, the intent was to define very specific criteria that covered critical reentry flight characteristics to be demonstrated to qualify full-scale RLV heat shield components. At this time, it was also determined that the all or nothing nature of the fifteen flight program could be broken up into three blocks of five flights with the technical and operations criteria included in the first block of five flights. This concession was made as a consequence of the Lockheed Martin commitment to add $75M to their contribution to the program. The fundamental requirement for fifteen flights remains in the program. As a result of the rules for payment of milestones in this Cooperative Agreement, all criteria must be met prior to payment and no milestone payment can be made out of sequence. Therefore, if within the first five flights the technical and operations criteria are not completed, no milestone payment will be made.

We believe it is therefore inappropriate to imply that the X-33 performance objectives have been reduced.

See comment 6, p. 34.

International Space Station (ISS) Servicing Requirements:
The ISS requirements for resupply flights of all international partners shall be accomplished in a way to ensure that microgravity science periods will be maintained. Any market analysis by VentureStar™ LLC, or any other RLV company would conclude that this requirement must be met by any proposed new system.

The statements that indicate "the more frequent docking activities could interfere with scientific endeavors" are not supported by current plans.

See comment 7, p. 34.

Lockheed Martin Industry Team Responsibilities:
The X-33 Industry Team led by the Lockheed Martin Skunk Works includes: Boeing Rocketdyne provides the Aerospike Engine; Allied Signal provides avionics, mechanical systems and flight software; BF Goodrich Aerospace provides the Thermal Protection System; and Sverdrup construction of the X-33 Flight Operations Facility. Lockheed Martin is responsible for the overall design, integration, test and X-33 operations. The Team is also designing the VentureStar™ and demonstrating critical SSTO technologies that can assist in reaching a decision to develop the VentureStar™ by the end of the X-33 Program.

3

See p. 22.

- **GAO Recommendation:**
In light of NASA's large investment in the X-33 Program and the important role the program plays in NASA's future plans, we recommend that the NASA Administrator include in the agency's Fiscal Year 2001 Performance Plan, performance targets for the X-33 Program which establish a clear path leading from the X-33 flight-test vehicle to an operational RLV and show progress toward meeting the agency's objective of significantly reducing launch costs.

NASA's Response:
Concur. Due to the importance of the X-33 Program to the Agency, we will include performance targets in NASA's Fiscal Year (FY) 2001 Performance Plan. Currently, in our FY 2000 Performance Plan, we include performance targets for the X-33 Program. These targets are presently tracked as a performance measurement objective for the Aero-Space Technology Enterprise. We will continue to place an increasingly higher priority on establishing performance targets that will lead to an operational RLV.

No comment.

General Comment:

Industry Loss of Profit and G&A
It should be noted that as a result of the cooperative agreement being a partnership, industry partners on the X-33 Program have foregone profit and G&A in the amount of approximately $240M. Profit would have been approximately $100M and the G&A would have been approximately $140M.

See comment 7, p. 34.

Editorial Comments:

Performance Objectives Revised (Page 13, Paragraph 1):
As Currently Written:
Technical problems and schedule constraints led Lockheed Martin and NASA to change two X-33 program objectives. First, Lockheed Martin exercised its option under the cooperative agreement to use an internal oxygen tank made of aluminum for the X-33 vehicle, instead of the lightweight composite materials used for the internal liquid hydrogen tank. An operational VentureStar™ will require a lightweight composite liquid oxygen tank to reduce the vehicle's weight and achieve SSTO operations.

Recommended Rewrite:
Lack of LOX compatibility test maturity one month after program go-ahead led Lockheed Martin to exercise its option under the cooperative agreement to use an internal liquid oxygen tank made of aluminum for the X-33 vehicle, instead of the lightweight composite materials used for the internal liquid hydrogen tank. An operational

4

VentureStar™ RLV may require a lightweight composite liquid oxygen tank to reduce the vehicle's weight and achieve SSTO operations. LOX compatibility testing continues through the ground-based program progressing in size from coupons to larger size tanks.

NASA and Lockheed Martin Financial Obligations and Oversight Roles (Page 15, Paragraph 1):
As Currently Written:
The X-33 cooperative agreement establishes a partnership business relationship between NASA and Lockheed Martin. The agreement assigns to Lockheed Martin responsibility for managing and implementing the X-33 Program, ...

Recommended Rewrite:
The X-33 cooperative agreement establishes a partnership business relationship between NASA and Lockheed Martin. Changes to the cooperative agreement require bilateral agreement. The agreement assigns to Lockheed Martin responsibility for managing and implementing the X-33 Program, ...

NASA Oversight Changed (Page 17, Paragraph 3):
As Currently Written:
NASA's X-33 program office has taken specific oversight actions in response to problems with the program. In one case, the program office withheld a $6.5 million payment when technical problems caused delays in fabricating the X-33 vehicle's engines. Only after the technical problems were resolved and the performance milestone met did NASA provide the funds. In another action, the program office notified Lockheed Martin the agency planned to withhold $500,000 from its next milestone payment because the company's system integration work on the X-33 Program was inadequate.

Recommended Rewrite:
NASA's X-33 program office has taken specific actions in response to problems with the program. For example, since the cooperative agreement was written to provide that milestone payments are made only after performance criteria have been met, independent of when the milestones are scheduled for completion, the program office therefore withholds all subsequent milestone payments until satisfactory accomplishment of performance criteria. In another action, the program office notified Lockheed Martin the agency planned to withhold $500,000 from all subsequent milestone payment because the company's system integration work on the X-33 Program was inadequate.

Government Support of VentureStar™ Vehicles (Page 20, Paragraph 1):
As Currently Written
Reference is made to "government financial support"; and/or, "government support" which appear a few times in this paragraph.

Recommended Rewrite:
Recommend replacing, "government financial support"; with, "government incentives".

5

Note: The appropriate role(s) of the government to help ensure a positive "Go" decision for the privately financed and commercially operated next generation reusable launch vehicle at the end of the decade is an area that has required significant coordination and understanding among government and industry personnel. This role the government might participate in could take the form of various government incentives or a mix of incentives like; tax incentives, tax holiday, government participation in funding portions of DDT&E, loan guarantees, etc.; all of which are risk reductions for the program.

Effects on Lockheed Martin's Cooperative Agreement Costs (Page 8, Paragraph 1; Page 9, Table 1; Page 11, Table 2):
As Currently Written:
Much of this discussion talks about "costs" both in the narrative as well as the tables that are referenced.

Recommended Rewrite:
Recommend replacing, "costs" or "industry costs"; with, "contribution" or "industry contribution".

Note: This approach seems to establish more clearly that industry is contributing their share and that any cost growth is born by our industry partner, the recipient, Lockheed Martin.

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The following are GAO's evaluations of the National Aeronautics and Space Administration's (NASA) letter dated July 1, 1999.

GAO Comments

1. We continue to believe that flight delays may affect NASA's investment plans for future space-launch programs. As indicated in this report, one of the key issues facing NASA is whether X-33 Program results provide confidence that risks have been reduced. We believe that the feasibility of transferring the key technologies demonstrated on the X-33 to an RLV such as the Venture Star cannot be adequately known until flights have been completed and results analyzed; and that it will be challenging to do so in a flight-test program which has been reduced from 10 to 3 months.

2. We agree with NASA's point that Lockheed Martin is not receiving a unique benefit. Our purpose in identifying IRAD costs and estimated reimbursements is to provide clarification on the total estimated costs that will be incurred by the government beyond that identified in the X-33 cooperative agreement, including potential reimbursement of industry IRAD costs. We also agree with NASA that inference should not be drawn that Lockheed Martin, or its partners, will recover most of their costs; actual reimbursement will be subject to an audit or review to ascertain the portion of the contribution allocable to government contracts. We have modified the text to reflect the need for such an audit.

3. We agree that NASA has historically excluded personnel costs from its research and development program budgets. Our purpose is to report as completely as possible the government's total costs for the X-33 Program. Thus, costs for NASA's personnel working on the X-33 Program are included in our report.

4. We revised the text to include the points raised in NASA's comments.

5. We believe the report accurately presents the history and status of these X-33 program performance objectives. In discussing the impact of technical problems on the X-33 Program performance objectives, our report identifies both the allowable change to an aluminum liquid oxygen tank and the reduction in flight speed. Our report is consistent with NASA's position. We clearly state that the X-33 Program may demonstrate the technical, operations, and business feasibility of a SSTO RLV, but at a lower speed. In addition, we provide similar information with regards to the breaking up of the flight program and associated payment conditions.

6. As noted in our report, NASA currently plans to make five shuttle flights per year to the station, and each shuttle flight can carry 34,200 pounds of payload (supplies and personnel) to the space station. Our report also notes that Venture Star RLVs will be able to carry an estimated 25,800 pounds of payload to the space station, must carry supplies and passengers on separate flights while shuttles can carry both on a single flight, and will have fewer on-orbit operational capabilities than the shuttle. NASA officials estimate that between two and three Venture Star flights will be required to replace each shuttle flight. Further, NASA's space station planning document, titled Requirements Data Set for ISS (International Space Station) Crew and Cargo Carriers for Reusable Launch Vehicle (RLV) Phase A Study (December 16, 1998) identifies RLV impacts on science operations as a potential concern. We, therefore, believe that the additional 5 to 10 annual Venture Star docking operations could potentially impact science operations now scheduled to occur during quiet periods between five annual shuttle docking operations. We believe the potential for disruptions will be determined, in part, by the number and scheduling of resupply flights. Given those uncertainties at this time, we continue to believe that science operations may be affected. We changed the text to reflect the potential net effect—that the amount of stable time available for conducting scientific operations may be reduced.

7. We revised the text to incorporate these comments as appropriate.

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